NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

DEVELOPMENT OF NATOPS
PERFORMANCE SOFTWARE
FOR THE H-46D HELICOPTER

by

John Michael Caram

March 1985

Thesis Advisor: D. M. Layton

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Development of NATOPS Performance Software for the H-46D Helicopter		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis March 1985 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John Michael Caram		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943		12. REPORT DATE March 1985 13. NUMBER OF PAGES 73
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) NATOPS Computerization Performance Planning Flight Planning HP-41 Programs H-46D Helicopter Numerical Regression Curve Fitting NATOPS Software		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This thesis generates closed-form equations for significant and frequently used NATOPS performance charts for the H-46D and H-46A (with T58-GE-10 engines) helicopters. These equations are developed into interactive software for the Hewlett-Packard HP-41CV hand-held programmable calculator. With this software installed in the calculator the user is able to calculate numerous NATOPS performance parameters (expeditiously, with reduced risk of error) both prior to and in flight.		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

Development of NATOPS Performance Software for the H-46D Helicopter

by

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MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1985

ABSTRACT

This thesis generates closed-form equations for significant and frequently used NATOPS performance charts for the H-46D and H-46A (with T58-GE-10 engines) helicopters. These equations are developed into interactive software for the Hewlett-Packard HP-41CV hand-held programmable calculator. With this software installed in the calculator the user is able to calculate numerous NATOPS performance parameters (expeditiously, with reduced risk of error) both prior to and in flight.

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ACKNOWLEDGEMENTS

The support of my wife, Joette, was instrumental in the completion of this thesis.

I. INTRODUCTION

A. COORDINATION OF EFFORT

A similar software development for the H-3D and H-3H helicopters was conducted at the same time as this development by Curtis [Ref. 1]. Because of the nature and complexity of the problem, the initial stages of these investigations were a joint effort. As a result, the Approach to the Problem (Chapter II) and the basic method of the Solution (Chapter III) of this work and of Reference 1 are very similar.

B. BACKGROUND

Performance planning is an essential task to ensure the safe conduct of any aircraft and crew during their flight. Naval aircrew use the Naval Air Training and Operating Procedure Standardization (NATOPS) manual to acquire all necessary performance data. For the most part, NATOPS performance information is presented in a graphical format often requiring the user to transit several subcharts, which may be located on different pages, to obtain the desired performance parameter. This procedure is time consuming, prone to error, and impractical in-flight.

The purpose of this thesis is to propose a correction to these NATOPS deficiencies by transforming selected performance charts into interactive, user-friendly, computer software for a hand-held programmable calculator. This solution would enable aircrew to obtain performance data with increased accuracy, reduced time and effort, and permit in-flight use.

Previously there have been several successful efforts in NATOPS computerization. The most recent study [Ref. 2] developed software for the A-6 aircraft utilizing the Hewlett-Packard HP-41CV hand-held programmable calculator. This research demonstrated the feasibility of NATOPS computerization and was a prime motivator for this thesis.

C. GOALS

The first goal of this study was to generate a closed-form equation for each selected NATOPS chart or subchart. The equations were required to be of a form such that independent variables were the specific chart input parameters and the dependent variable, the output parameter. The equations used to "fit" each NATOPS chart had to allow an explicit calculation of the dependent variable. Furthermore, they had to consist of standard functions (no differentials/integral equations) which could be programmed on a calculator or computer.

Once the equations representing the performance charts had been derived, it was necessary to select the hardware which would be used for software design. The HP-41CV programmable calculator was selected due to its small size, relatively large memory capability (6.4 Kbytes), and successful use in the past.

Upon completion of the software development the ultimate goal of this research was the testing and implementation of the end product into the fleet.

II. APPROACH TO THE PROBLEM

The first and foremost problem encountered was the generation of the closed-form equation in a manner which accurately represented each performance chart with a minimum number of terms. For the majority of charts considered there were two independent input variables that yielded a single dependent output variable. This was visualized as a three dimensional surface in space.

To accomplish fitting an equation to a surface of irregular nature required the utilization of a numerical regression routine. These routines are numerous and have been developed into several software packages for main frame computers. The software chosen for this study was the Biomedical Computer Program (BMDP) statistical package [Ref. 3], installed on an IBM 3033 main frame computer located at the Naval Postgraduate School in Monterey, California. A regression is linear in nature no matter how many independent variables are involved. However, nonlinear functions may be used in a regression if they are first "linearized". For example, if the nonlinear functions x^2, x^3, and $\ln(x)$ are transformed into indepentent variables (transforms) U, Y, and Z, respectively, then a regression can be performed to yield an equation of the form:

$$S = aU + bY + cZ + d \qquad \text{(eqn 2.1)}$$

where a, b, and c, are the regression coefficients, d is the intercept, and S is the dependent variable. The specific BMDP routine used for the majority of charts analyzed was the "all possible subset" multiple regression routine (P9R) which allows the user to input a large selection of

transformed independent variables to be examined during the regression analysis. The P9R could be selected to either use all transformed variables offered (method is none), or perform the regression selecting subsets of the offered transforms and output the subset with the best fit statistics (method is CP).

The dominating criteria used to determine the best fit statistics was the squared multiple regression correlation (R^2). Accuracy was gauged by how close R^2 was to the ideal value of 1.0. The required R^2 for an acceptable fit was found to vary between performance charts, and was a function of what dependent output variable was being generated, the irregularity of the surface, and the number of independent input variables. For each chart multiple regression analyses were performed varying the offered transforms in number and/or type, until a closed form equation was generated that yielded output that was within the accuracy of manual chart interpolation.

The accuracy with which NATOPS chart could be read was subject to the individual chart's characteristics, but in general the following tolerances for dependent variables were established (for the regression analysis).

airspeed: within 2 knots
altitude: within 100 feet
weight: within 150 pounds
torque: within 1 %
distance: within 1 mile
time: within .1 hour

Prior to the execution of the regression program, a data file for each surface was created. The file consisted of data sets which were merely the independent variable values and the corresponding dependent variable value. For a three dimensional surface each data set consisted of three values. It was critical to ensure that the data sets extracted from

a performance chart were as accurate as possible and that the data file clearly defined the surface. Obviously, those surfaces that were irregular in nature required significantly more data sets than smoother or more "well behaved" surfaces. If a surface contained a sharp point or discontinuity, this portion of the surface was eliminated from the regression analysis due to the inability of the software to accurately fit abberations.

The tranformed variable selection was the key to successful regression analysis. Through experience one gained an intuitive feel for what type of transformed variables would yield a close fit to a surface. Fortunately, most of the surfaces responded well to regression analysis utilizing combinations of the independent variables raised to powers between one and four (polonomial regression). A standard polonomial regression program was developed containing all the possible polonomial terms up to the fourth order, for three and four dimensional surfaces.

For a few surfaces, obtaining a close fit by regression analysis incurred the penalty of retaining a large number of transformed terms. An alternative to this was to fit each of the depicted influence curves and develop the final computer software to interpolate between curves. The trade off with an interpolation scheme was increased accuracy at the expense of inordinate program size and complexity, causing the result to be unacceptable. In a few cases it became necessary to use nonlinear transforms of the independent variables such as exponentials, and high order fractional combinations of terms (Appendix B: pp. 64-65).

On the first execution of each regression analysis "method is none" was selected in the P9R program. This keyed the BMDP software to use all the offered transforms for the regression analysis. During execution, matrix algebra was performed with the independent variables and

transforms. If this algebra created numbers outside the tolerance range specified in the program (default tolerance = .0001), the "method is none" option would eliminate the offending variable, or transform, and continue execution. The resulting output contained the R^2 value along with other fit statistics and listed all terms eliminated for low tolerance. Performing a second iteration with the out-of-tolerance transforms eliminated, and with "method is CP" selected, allowed the BMDP software to analyze subsets of the remaining transforms. Performing this two step process yielded the best fit with fewest terms for each surface.

III. THE SOLUTION

The polonomial transform program yielded acceptable regression results in the majority of cases. For the performance charts that had difficult surfaces to fit, requiring as many as 38 transformed terms (Appendix B: p. 58), it was found to be advantageous to take the penalty of a large regression equation rather than fitting influence lines and interpolating between them. Of all the surfaces considered (23), only the single engine envelope (Appendix B: p. 64) required nonlinear transformed terms, specifically exponential and high order fractions.

A. EXAMPLE SURFACE REGRESSION ANALYSIS

The engine performance chart Figure 3.1 was chosen to illustrate the regression technique since it demonstrated the capability of numerical regression to generate an accurate closed form equation of a fairly irregular surface.

The first step in the solution of this performance chart was to create the data file for the regression program. Data sets were taken along each pressure altitude influence line at increments of 10° centigrade (C) with additional points added for the 4000 to 6000 foot altitude lines, due to their close proximity to each other. Each of the 155 data sets consisted of two independent variables (temperature and altitude) and the resulting dependent variable (torque). The sea level altitude line was omitted since it could be calculated directly (linear equation) and due to its discontinuities at -5 and 15 °C causing difficulties in fitting the surface.

Next a numerical regression was performed with the "method is none" option selected utilizing the standard fourth order polonomial (22 transforms) discussed earlier. The resulting output listed the terms excluded from the regression analysis due to exceeding tolerance limits (4), the regression R^2 (.99942), and other fit statistics. The high R^2 value indicated that the selected polonomial transforms were representative of the surface.

The next step was to determine if some of the retained transforms could be eliminated without significantly effecting the fit. The four out-of-tolerance terms were deleted from the transform selection and the program was executed with the "method is CP" option in effect. This resulted in an elimination of eight transforms while only degrading the R^2 value to .99936 (Appendix B: p. 36).

The equation for the surface was tested by writing a program stub and checked to ensure accuracy. Since the surface fit did not consider altitudes below the 2000 foot line, an interpolation routine was required in the final program to calculate torque when pressure altitude was between 2000 feet and sea level.

MODEL H 46D
ROTOR RPM 100 PERCENT
ENGINES (1) T58 GE 10
FUEL GRADE JP 4 JP 5
DATA BASIS FLIGHT TEST VERTOL REPORT A02AD005 DATED 3 MARCH 1967

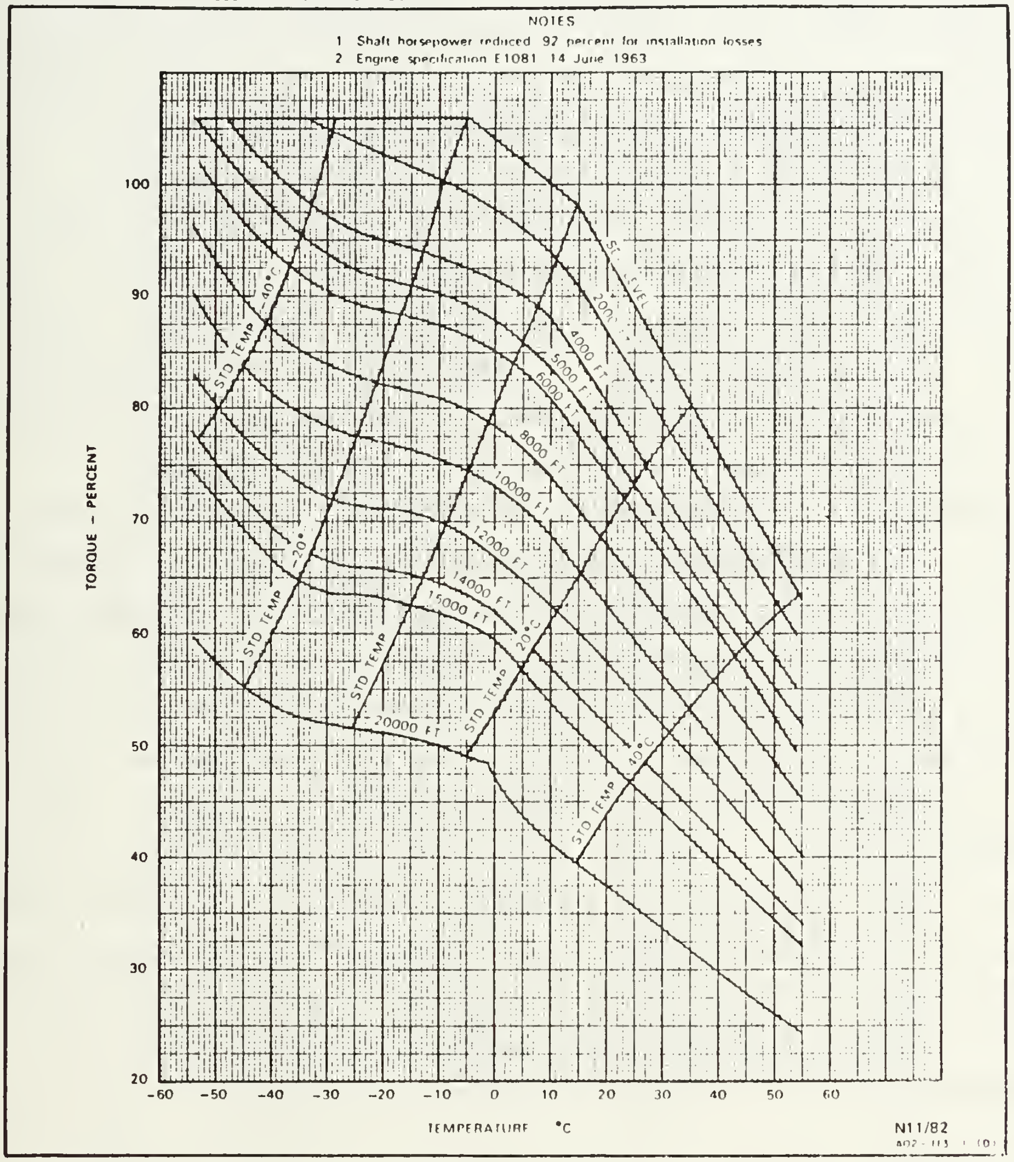

Figure 11-1A. Engine Performance (Military Power — 100 Percent N_r)

Figure 3.1 Engine Performance (Military Power - 100% Nr)

IV. RESULTS

At the onset of this study 10 different NATOPS performance charts were selected for computerization based on their significance and frequency of use. It was anticipated that the final performance chart programs would be too voluminous to be collectively stored within the HP-41CV memory. This would necessitate using an external mass storage device or executing individual programs piecemeal. Both of these alternatives would have had serious degrading effects, forcing the only other alternative of contracting Hewlett-Packard to hardwire one or more plug-in read-only-memory (ROM) modules containing the NATOPS software.

Fortunately, the majority of programs were reasonable in length. With efficient programming techniques employed, and two external memory modules in series with an extended functions module (total memory of 6.4 Kbytes), it became evident that all programs could be simultaneously stored within the calculator. With this in mind a master program was written which functioned as a software manager which assigned performance charts to key locations (Appendix A), called programs from inexecutable extended memory to the executable work space in main memory, and interactively communicated with the user. In general the master program functioned as a communications system and manager between the user and performance chart software in an interactive and user-friendly mode.

Appendix A contains the simple user instructions to execute any of the 10 listed NATOPS charts desired. With a printer attached a complete performance profile can be executed and printed for any mission plan. Appendix B lists all surface regression equations, flow charts, and program

code. It should be noted that the regression equations can be programmed for use with any capable system. The results presented here are for the H-46D and modified H-46A (with T58-GE-10 engines) NATOPS performance charts referenced in Appendix A. Future modification of these charts would invalidate the performance software for those paticular charts.

V. CONCLUSIONS AND RECOMMENDATIONS

From the results of this thesis it can be concluded that graphical NATOPS performance data can be computerized. To effectively accomplish this, computer oriented numerical regression routines must be utilized to generate closed-form equations.

Once the equations have been derived, computer software can be developed that executes the programs in an expeditious, accurate, and portable fashion. Furthermore, this software can be designed for virtually any type of computer from hand-held programmable calculators to personal computers.

It is recommended that the NATOPS performance software developed in this study be submitted to a fleet squadron or Fleet Replacement Squadron (FRS) for test and evaluation. Since the software can be utilized as is, with off the shelf Hewlett-Packard components, the cost of testing would be minimized. If this software proved to be fleet applicable, Hewlett-Packard should be contracted to develop plug-in application modules which would increase reliability and decrease execution time.

APPENDIX A

NATOPS PERFORMANCE SOFTWARE USER'S GUIDE

A. BASIC USE

The NATOPS performance software designed for the HP-41CV calculator is simple and expeditious to use. The calculator keyboard configuration is depicted in Figure A.1. As you can see the first top two rows have abbreviated program names under the keys. The exact meaning of each performance chart abbreviation and its NATOPS [Ref. 4] page reference are contained in Table I below.

TABLE I

NATOPS Performance Chart Reference

HP-41CV ABBREVIATION	NATOPS CHART TITLE	NATOPS PAGE NUMBER
DA	Density Altitude Chart	11-3
TQAV	Engine Performance Chart (Military Power 100% Nr)	11-5
HIGW	Max Gross Weight for Hovering in Ground Effect	11-9
VTOGW	Max Gross Weight for Vertical Takeoff	11-11
HITQ	Torque Required to Hover in Ground Effect	11-12
HOTQ	Torque Required to Hover Out of Ground Effect	11-13
SE/EV	Ability to Maintain Flight One Engine Operating (100% Nr)	11-37
RNG	Max Range (100% Nr)	11-22/3
VNE	Indicated Never Exceed Speed	1-173
END	Max Level Flight Endurance	11-32/3

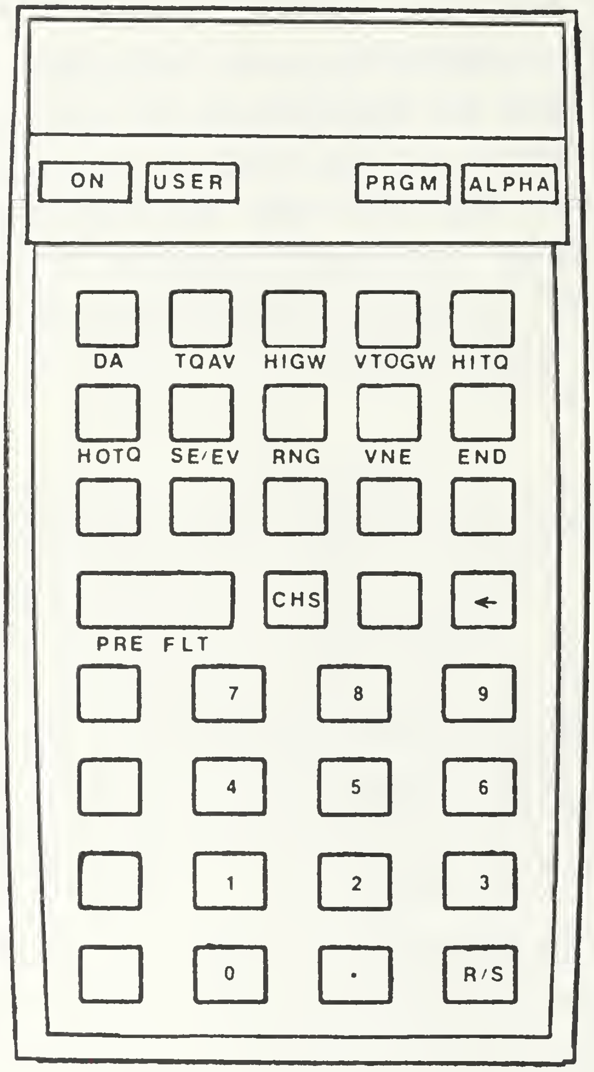

Figure A.1 Hewlett-Packard HP-41CV Calculator

The programs listed in Table I are assigned to the corresponding keys shown in Figure A.1. The key marked "PRE FLT" performs all 10 programs and produces a hard copy of the output. This program requires that a printer is attached. To execute a program follow the steps presented below.

1. Turn the calculator on.
2. Ensure the calculator is in the user mode, if the word user is not visible in the display push the user key.
3. Find the key with the paticular performance chart desired and push it. As the program is initiated the calculator will prompt the user for any needed information. The exact prompt meanings are defined below:
   - PA? FT - pressure altitude in ft.
   - OAT? C - outside air temperature in °C.
   - GW? LBS - gross weight in lbs.
   - WIND? KTS - head wind in kts.
   - CLIMB? FPM - climb rate in ft. per min.
   - FUEL? LBS - fuel on board in lbs.
4. Answer the prompt by pushing the corresponding numbered keys until the desired value is seen in the display. If a mistake is made, simply push the key with the horizontal arrow (far right column four keys from the top) and re-enter the number. If the number to be entered is negative (negative OAT), push the key marked CHS after the number has been entered in the display. When the desired number is displayed in the window push the key marked R/S (run/stop, bottom right key).
5. After all the prompts required have been answered the calculator will execute the program. While the calcualtor is working "PRGM" will be visible in the display. As the calculator generates answers they

are shown in the display. Some charts yield more than one performance parameter, so it is necessary to note each parameter displayed and then push the R/S key to continue execution.

6. Once all performance parameters have been calculated pushing R/S will display "NEXT" which tells the user he has been given all available output and the calculator is ready to execute the next program.
7. Before executing the PRE FLT program ensure the calculator is turned off. With the printer also turned off plug the printer input chord into the only remaining extension port. Turn the calculator and printer on, select the normal mode on the printer, and push the PRE FLT key. All other instructions remain the same.

B. GENERAL USER INFORMATION

The NATOPS software should generate accurate answers within the range of a selected performance chart. If data is entered erroneously, or in excess of a paticular chart's range, the output will be in error.

In the cases where a chart has limitations such as density altitude [Ref. 4: p. 11-9], these have been taken into account within the program and the output will tell the user if they exceed that limitation. If the user is ever in doubt as to the validity of the calculator generated performance data, the NATOPS should be consulted.

C. INITIAL CALCULATOR PREPARATION

The basic use instructions assume the user has a calcualator that has all the performance software installed. If the user merely has the calculator (with two extended memory modules, and an extended functions module), a card reader,

and the NATOPS software program cards; several steps must be taken before the calculator can be used as described earlier.

1. Become familiar with the HP-41CV owner's manual and all peripherals operating instructions. While the basic user can avoid an in depth knowledge of the system, the initial set up requires someone who is familiar with the hardware and procedures listed in [Refs. 5,6,7].
2. With the extended memory and extended functions modules in their proper ports, and the card reader attached, loading the programs into main and extended memory can begin.
   - Load the following programs into extended memory: HIGW, VTOGW, HITQ, HOTQ, SE/EV, VNE, RNG, ENDA, and ENDB.
   - Load the following programs into main memory (in the order listed): MAIN, QD, DA, and TQAV.
3. Ensure the only programs in main memory are the ones listed above and erase any other programs.
4. Pack the programs in main memory.
5. Execute the program MAIN.

The calcualator is now loaded and positioned to the main program. By pressing the user key the performance programs are assigned to their respective key locations and the calculator is ready for program execution.

APPENDIX B

REGRESSION EQUATIONS AND SOFTWARE DOCUMENTATIONS

This appendix contains all of the regression equations generated for each NATOPS chart, associated flow charts, and resulting computer code. For the most part, the regression equations are listed in a tabular form due to their size. The actual equations are of the form shown in equation 2.1 The R^2 and standard error fo estimate for each regression is also listed. The standard error of estimate is the average error expected over one standard deviation of the surface's area. The flow charts use standard symbology and depict the general programming logic but are not detailed in nature. The computer code listings are in the Reverse Polish Notation (RPN) language developed by Hewlett-Packard.

Table II lists all the variables used in the regresion equations throughout the programs. Table III lists the programming flags used and their definitions. The following is a listing of memory storage registers and their contents.

REGISTER	VARIABLE/TRANSFORM
00	A
01	A^2
02	A^3
03	A^4
04	B
05	B^2
06	B^3
07	B^4
08	C
09	C^2
10	C^3
11	C^4
12	D
13	D^2
14	D^3
15	D^4
16	E
17	E^2
18	E^3
19	E^4
20	F
21	G
22	scratch

REGISTER	VARIABLE/TRANSFORM
23	scratch
24	scratch
25	scratch
26	scratch
27	scratch
28	scratch
29	scratch
30	scratch
31	scratch

TABLE II

Variable Definitions

VARIABLE	DEFINITION
A	(Pressure Altitude)/1000
B	(Oatside Air Temperature)/1000
C	(Gross Weight)/1000
D	(Density Altitude)/1000
E	Wind
F	(Fuel)/100
G	(Vertical Climb)/10
H	(Torque Available)/100
I	Standard temperature (END)
J	Base Line Gross Weight No Wind (HIGW)
K	Base Line Gross Weight No Wind (VTOGW)
L	Base Line Gross Weight No Climb (VTOGW)
M	Base Line Average Torque (HITQ)
N	Base Line Average Torque (HOTQ)
P	Base Line Unit Range (RNG)
Q	Unit Range (RNG)
R	Base Line Indicated Airspeed (RNG)
T	Base Line Time (END)
U	Base Line Torque (SE/EV)

TABLE III

Flag Definitions

FLAG	DEFINITIONS
01	Pre Flt program in execution
02	Do not display register contents
03	Recalculate endurance for new weight (END)
21	Print a hard copy of results

A. MASTER PROGRAM (MAIN)

1. Equations- This program serves as the software manager and and doe not contain equations in itself.

2. Flowchart- See Figure B.1.

3. Program listing- See pages 31-32.

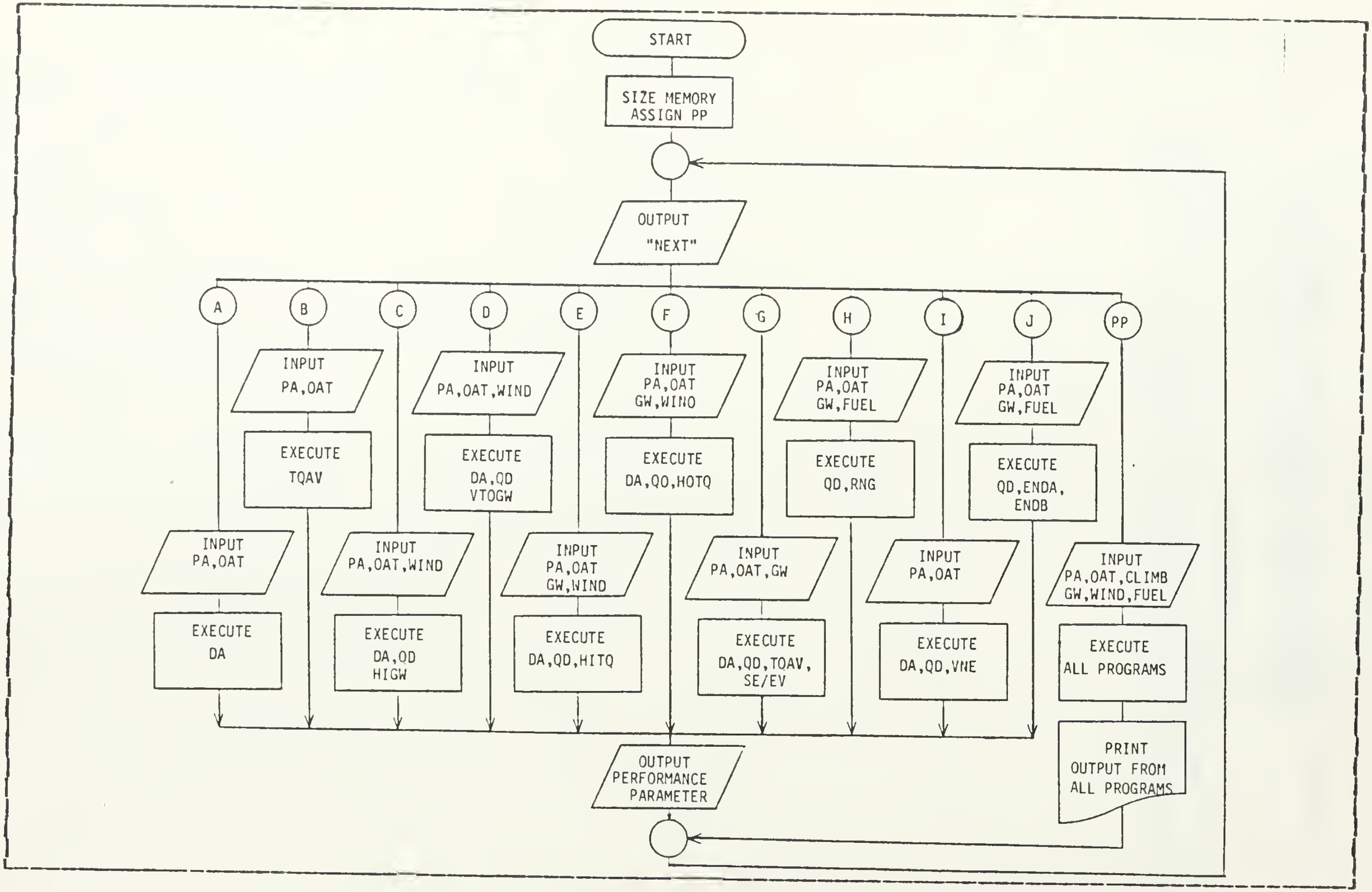

Figure B.1 MAIN Flowchart

```
01♦LBL "MAIN"
02 32
03 PSIZE
04 41
05 "PP"
06 PASN
07♦LBL 13
08 ADV
09 ADV
10 FIX 0
11 "NEXT"
12 PROMPT
13♦LBL A
14 XEQ 06
15 XEQ "DA"
16 ADV
17 PROMPT
18 GTO 13
19♦LBL B
20 XEQ 06
21 XEQ "TQAV"
22 PROMPT
23 GTO 13
24♦LBL C
25 XEQ 08
26 "HIGW"
27 GETP
28 XEQ "HIGW"
29 PROMPT
30 GTO 13
31♦LBL D
32 XEQ 08
33 "VTOGW"
34 GETP
35 XEQ "VTOGW"
36 PROMPT
37 GTO 13
38♦LBL E
39 XEQ 10
40 "HITQ"
41 GETP
42 XEQ "HITQ"
43 PROMPT
44 GTO 13
45♦LBL F
46 XEQ 10
47 "HOTQ"
48 GETP
49 XEQ "HOTQ"
50 PROMPT
51 GTO 13
52♦LBL G
53 XEQ 09
54 XEQ "TQAV"
55 "SE/EV"
56 GETP
57 XEQ "SE/EV"
58 PROMPT
59 GTO 13
60♦LBL H
61 XEQ 07
62 XEQ 11
63 "RNG"
64 GETP
65 XEQ "RNG"
66 PROMPT
67 GTO 13
68♦LBL I
69 XEQ 09
70 "VNE"
71 GETP
72 XEQ "VNE"
73 PROMPT
74 GTO 13
75♦LBL J
76 XEQ 07
77 XEQ 11
78 "ENDA"
79 GETP
80 XEQ "ENDA"
81 PROMPT
82 "ENDB"
83 GETP
84 XEQ "ENDB"
85 PROMPT
86 GTO 13
87♦LBL "PP"
88 FS? 21
89 GTO 14
90 "PTR REQ"
91 PROMPT
92 GTO 13
93♦LBL 14
94 SF 01
95 XEQ 10
96 "CLIMB? FPM"
97 PROMPT
98 10
99 /
100 STO 21
101 XEQ 11
102 RCL 12
103 1000
104 *
105 "DA="
106 ARCL X
107 ADV
108 PRA
109 XEQ "TQAV"
110 PRA
111 "HIGW"
112 GETP
113 XEQ "HIGW"
114 PRA
115 "VTOGW"
116 GETP
117 XEQ "VTOGW"
118 PRA
119 "HITQ"
120 GETP
121 XEQ "HITQ"
122 PRA
123 "HOTQ"
124 GETP
125 XEQ "HOTQ"
126 PRA
127 "SE/EV"
128 GETP
129 XEQ "SE/EV"
130 PRA
131 "RNG"
132 GETP
133 XEQ "RNG"
134 PRA
135 "VNE"
136 GETP
137 XEQ "VNE"
138 PRA
139 "ENDA"
140 GETP
141 XEQ "ENDA"
142 PRA
143 "ENDB"
144 GETP
145 XEQ "ENDB"
146 PRA
147 CF 01
148 GTO 13
149♦LBL 06
150 XEQ 01
```

```
151 XEQ 02
152 RTN
153♦LBL 07
154 XEQ 06
155 XEQ 03
156 RTN
157♦LBL 08
158 SF 02
159 XEQ 06
160 XEQ 05
161 XEQ "DA"
162 CF 02
163 RTN
164♦LBL 09
165 SF 02
166 FS? 01
167 CF 02
168 XEQ 07
169 XEQ "DA"
170 XEQ 04
171 CF 02
172 RTN
173♦LBL 10
174 XEQ 09
175 XEQ 05
176 RTN
177♦LBL 01
178 "PA?  FT"
179 PROMPT
180 1000
181 /
182 STO 00
183 01.003
184 XEQ "QD"
185 RTN
186♦LBL 02
187 "OAT?  C"
188 PROMPT
189 STO 04
190 05.007
191 XEQ "QD"
192 RTN
193♦LBL 03
194 "GW?  LBS"
195 PROMPT
196 1000
197 /
198 STO 08
199 09.011
200 XEQ "QD"
201 RTN
202♦LBL 04
203 RCL 12
204 13.015
205 XEQ "QD"
206 RTN
207♦LBL 05
208 "WIND? KTS"
209 PROMPT
210 STO 16
211 17.019
212 XEQ "QD"
213 RTN
214♦LBL 11
215 "FUEL?  LBS"
216 PROMPT
217 100
218 /
219 STO 20
220 END
```

```
01♦LBL "QD"
02 STO T
03 X<>Y
04 ENTER↑
05 ENTER↑
06 X↑2
07♦LBL 12
08 STO IND T
09 *
10 ISG T
11 GTO 12
12 END
```

B. DENSITY ALTITUDE (DA)

1. Equations- $DA = (1-a^{.234711})/6.863X10^{-3}$

   where $a = b/c$

   and $b = [1-6.863X10^{-3}(A)]^{5.260559}$

   and $c = (273.15+B)/288.15$

2. Flowchart- See Figure B.2.

3. Program listing- See page 35.

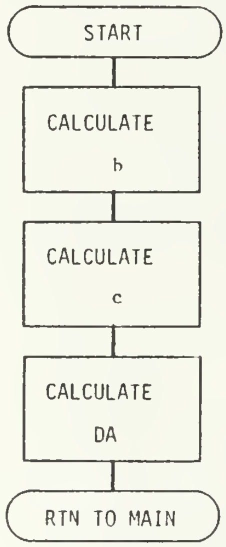

Figure B.2 DA Flowchart

```
01♦LBL "DA"
02 RCL 00
03 6.863 E-3
04 *
05 CHS
06 1
07 +
08 5.260559
09 Y↑X
10 RCL 04
11 273.15
12 +
13 288.15
14 /
15 /
16 .234711
17 Y↑X
18 CHS
19 1
20 +
21 6.863 E-3
22 /
23 STO 12
24 FS? 02
25 RTN
26 1000
27 *
28 "DA="
29 ARCL X
30 END
```

C. ENGINE PERFORMANCE (TQAV)

1. Equation/Fit statistics-

   Regression equation- For Figure 11-1A chart [Ref. 4 p. 11-5].

   $R^2 = .99936$

   Standard error of estimate = .539449 kts.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	104.758
A	-3.56893
B	-.394746
A^4B^2	$-.171715 \times 10^{-7}$
A^2	.0324431
A^2B	-.000340744
A^2B^2	.0000147638
A^2B^3	$.144471 \times 10^{-6}$
AB	.0107422
AB^4	$-.346277 \times 10^{-7}$
B^2	-.00809738
B^3	-.0000582075
B^4	$.189613 \times 10^{-5}$

2. Flowchart- See Figure B.3.

3. Program listing- See page 38.

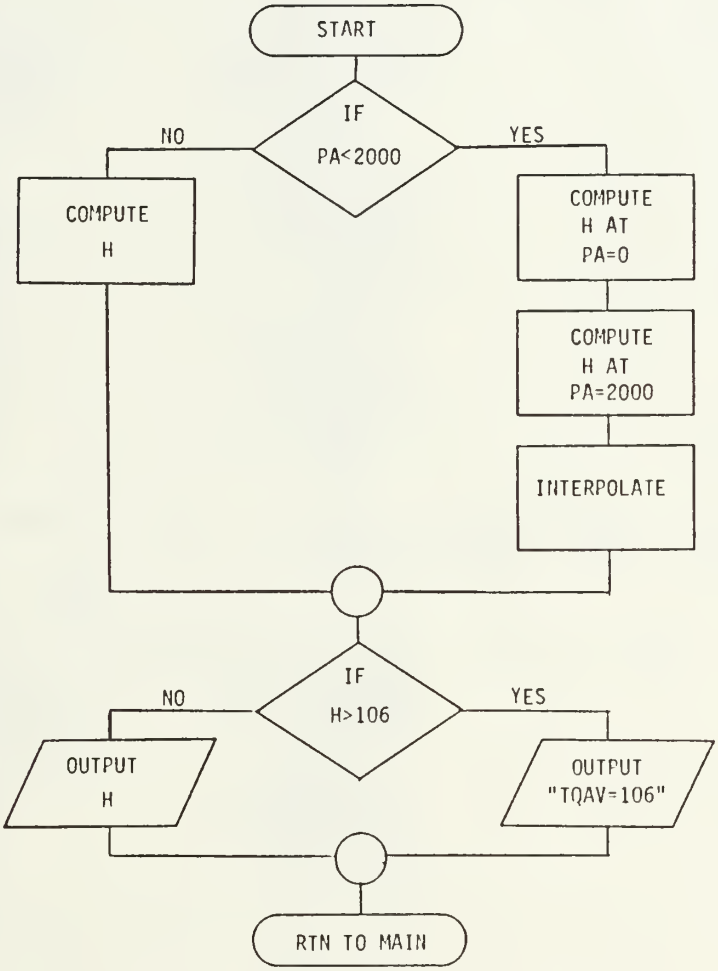

Figure B.3 TQAV Flowchart

```
♦LBL "TQAV"
RCL 00
STO 25
2.0
X>Y?
GTO 05
XEQ 01
GTO 10
♦LBL 05
-5.0
RCL 04
X<=Y?
GTO 02
15.0
RCL 04
X<=Y?
GTO 03
60
+
-.8625
*
162.6875
+
STO 23
GTO 07
♦LBL 03
60
+
-.4
*
128
+
STO 23
GTO 07
♦LBL 02
106.0
STO 23
♦LBL 07
2.0
STO 00
X↑2
STO 01
X↑2
STO 03
XEQ 01
STO 24
CHS
RCL 23
+
RCL 25
2.0
/
CHS
*
RCL 23
+
♦LBL 10
106.0
X<>Y
X>Y?
GTO 11
10
/
STO 22
FS? 02
RTN
10
*
"TQAV="
ARCL X
ADV
RTN
♦LBL 11
10.6
STO 22
FS? 02
RTN
"TQAV=106"
ADV
RTN
♦LBL 01
104.758
RCL 00
-3.56893
*
+
RCL 04
-.394746
*
+
RCL 03
RCL 05
*
-.171715 E-7
*
+
RCL 01
.0324431
*
+
RCL 01
RCL 04
*
-.00034074
*
+
RCL 01
RCL 05
*
.147638 E-4
*
+
RCL 01
RCL 06
*
.144471 E-6
*
+
RCL 00
RCL 04
*
.0107422
*
+
RCL 00
RCL 07
*
-.346277 E-7
*
+
RCL 05
-.00009738
*
+
RCL 06
-.582875 E-4
*
+
RCL 07
.189613 E-5
*
+
END
```

D. MAX GROSS WEIGHT FOR HOVERING (HIGH)

1. Equation/Fit statistics-

Regression equation- For Figure 11-4 top chart [Ref. 4 p. 11-9].

R^2 = .99888

Standard error of estimate = 128.142 lbs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	28.8369
B	-.104947
A	-.957611
B^4	$.236917\text{X}10^{-6}$
AB^4	$.738596\text{X}10^{-7}$
A^2B^4	$-.108756\text{X}10^{-7}$
A^3B^4	$.547916\text{X}10^{-9}$
AB^3	$-.231012\text{X}10^{-5}$
A^2B^3	$.167621\text{X}10^{-6}$
B^2	-.00209967
A^2B^2	.000015347
A^3B^2	$-.108395\text{X}10^{-5}$
A^2B	.000201287
A^4B	$-.852947\text{X}10^{-6}$
A^2	.00815863

Regression equation- For Figure 11-4 bottom chart [Ref. 4 p. 11-9].

R^2 = .99993

Standard error of estimate = 19.776 lbs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	.128617
J	.990746
E^2J	.000043718
EJ	.00283739
J^4	$.3069\text{X}10^{-6}$

2. Flowchart- See Figure B.4.

3. Program listing- See page 41.

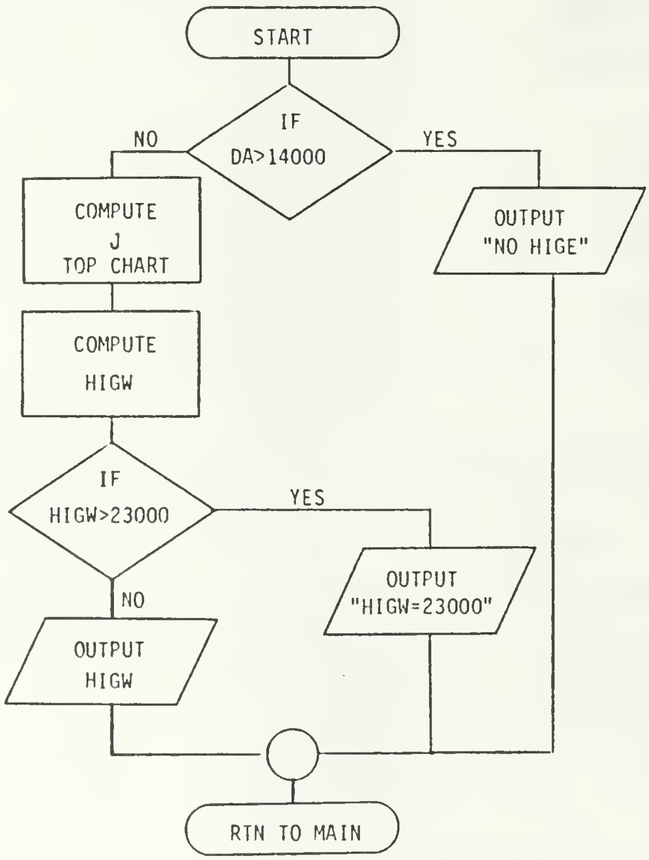

Figure B.4 HIGW Flowchart

```
01♦LBL "HIGW"
02 RCL 12
03 14
04 X>Y?
05 GTO 01
06 "NO HIGE"
07 ADV
08 RTN
09♦LBL 01
10 28.8369
11 RCL 04
12 -.104947
13 *
14 +
15 RCL 00
16 -.957611
17 *
18 +
19 RCL 07
20 .236917 E-6
21 *
22 +
23 RCL 07
24 RCL 00
25 *
26 .738596 E-7
27 *
28 +
29 RCL 07
30 RCL 01
31 *
32 -.108756 E-7
33 *
34 +
35 RCL 07
36 RCL 02
37 *
38 .547916 E-9
39 *
40 +
41 RCL 06
42 RCL 00
43 *
44 -.231012 E-5
45 *
46 +
47 RCL 06
48 RCL 01
49 *
50 .167621 E-6
51 *
52 +
53 RCL 05
54 -.00209967
55 *
56 +
57 RCL 05
58 RCL 01
59 *
60 .15347 E-4
61 *
62 +
63 RCL 05
64 RCL 02
65 *
66 -.108395 E-5
67 *
68 +
69 RCL 04
70 RCL 01
71 *
72 .000201287
73 *
74 +
75 RCL 04
76 RCL 03
77 *
78 -.852947 E-6
79 *
80 +
81 RCL 01
82 .00815863
83 *
84 +
85 STO 23
86 .990746
87 *
88 .128617
89 +
90 RCL 17
91 RCL 23
92 *
93 .43718 E-4
94 *
95 +
96 RCL 16
97 RCL 23
98 *
99 .00283739
100 *
101 +
102 RCL 23
103 4
104 Y↑X
105 .3069 E-6
106 *
107 +
108 23.0
109 X<=Y?
110 GTO 03
111 X<>Y
112 1000
113 *
114 "HIGW="
115 ARCL X
116 ADV
117 RTN
118♦LBL 03
119 "HIGW=23.000"
120 ADV
121 .END.
```

E. MAX GROSS WEIGHT FOR VERTICAL TAKEOFF (VTOGW)

1. Equation/Fit statistics-

Regression equation- For Figure 11-5 top chart discontinuity curve (CPA) [Ref. 4 p. 11-11].

$R^2 = .99923$

Standard error of estimate = 81.257 lbs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	3.72796
B	-.0954314
B^2	-.00188251
B^3	-.0000596998
B^4	$-.608172 \times 10^{-6}$

Regression equation- For Figure 11-5 top chart left of discontinuity [Ref. 4 p. 11-11].

$R^2 = .99919$

Standard error of estimate = 96.041 lbs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	26.1925
B	-.117656
A	-1.04142
B^4	$.311223 \times 10^{-6}$
A^4B^4	$.876216 \times 10^{-11}$
B^3	$-.734593 \times 10^{-5}$
A^4B^3	$.358246 \times 10^{-9}$
B^2	-.00147462
AB^2	.0000495106
A^2B^2	$-.451883 \times 10^{-5}$
AB	.0060469
A^2B	-.000282418
A^2	.0268048
A^3	-.000633067

Regression equation- For Figure 11-5 top chart right of discontinuity [Ref. 4 p. 11-11].

$R^2 = .99944$

Standard error of estimate = 12.521 lbs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	23.346
B	-.0155989
A	-.1907
B^4	$-.219767 \times 10^{-6}$
AB^4	$.389472 \times 10^{-8}$
B^3	$-.769256 \times 10^{-5}$
B^2	.000147492
A^2	-.00128983

Regression equation- For Figure 11-5 middle chart [Ref. 4 p. 11-11].

$R^2 = .99996$

Standard error of estimate = 32.545 lbs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	.00559456
E	-.0756063
K	.999707
E^3	$-.164715\times10^{-4}$
E^2K	.00038988
E^2K^2	$-.250156\times10^{-4}$
E^2K^4	$.234975\times10^{-7}$
EK	.0103111
EK^4	$-.220855\times10^{-6}$

Regression equation- For Figure 11-5 bottom chart [Ref. 4 p. 11-11].

$R^2 = .99996$

Standard error of estimate = 24.736 lbs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	.0278589
L	.998241
GL	-.00189451
GL^3	$.425897\times10^{-5}$
GL^4	$-.140897\times10^{-6}$

2. Flowchart- See Figure B.5.

3. Program listing- See page 45-46.

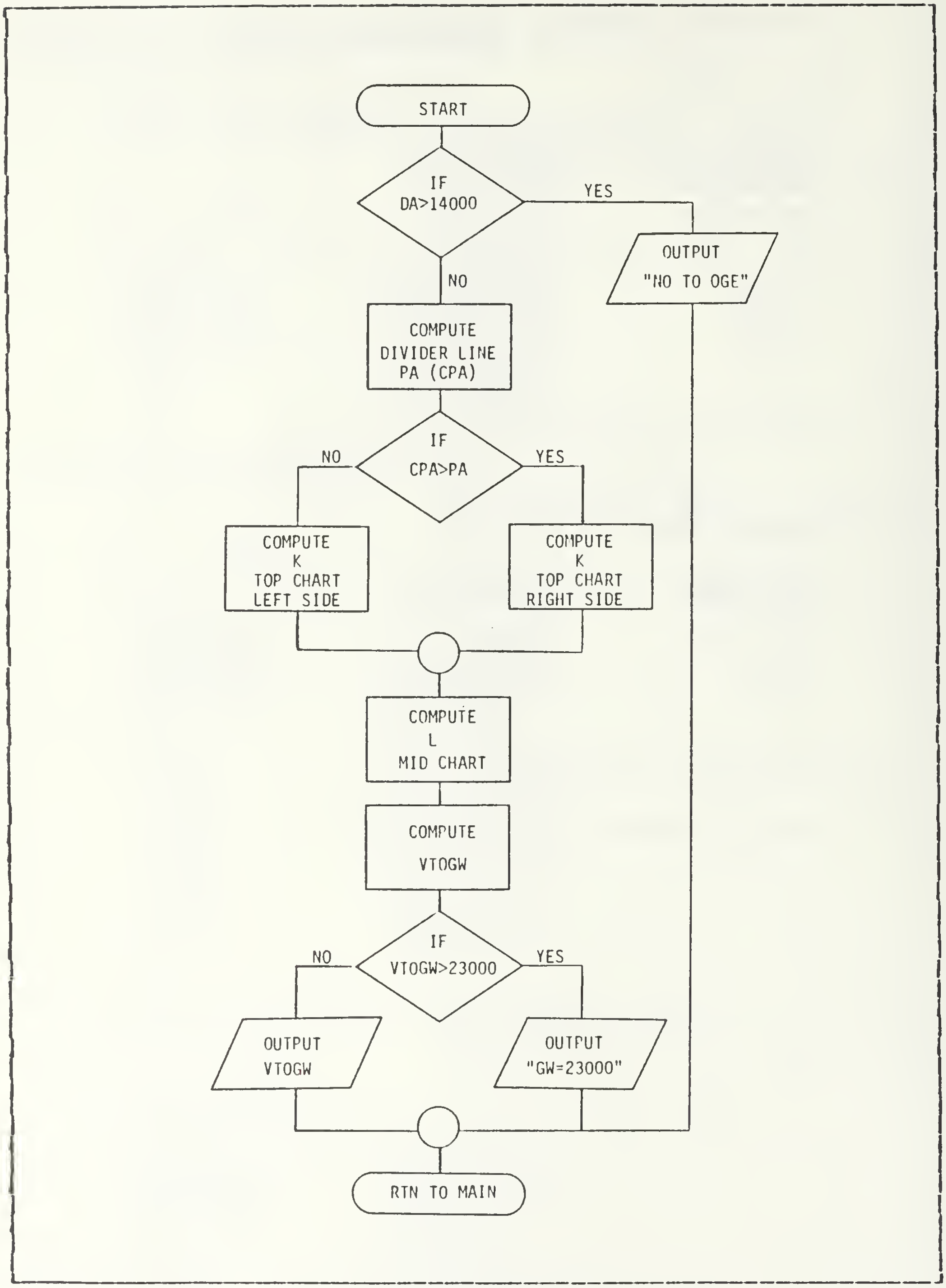

Figure B.5 VTOGW Flowchart

```
01♦LBL "VTOGW"
02 FS? 01
03 GTO 09
04 "CLIMB? FPM"
05 PROMPT
06 10
07 /
08 STO 21
09♦LBL 09
10 RCL 12
11 14
12 X>Y?
13 GTO 01
14 "NO VTO OGE"
15 ADV
16 RTN
17♦LBL 01
18 3.72796
19 RCL 04
20 -.0954314
21 *
22 +
23 RCL 05
24 -.00188251
25 *
26 +
27 RCL 06
28 -.596998 E-4
29 *
30 +
31 RCL 07
32 -.608172 E-6
33 *
34 +
35 STO 23
36 RCL 00
37 X<=Y?
38 GTO 03
39 26.1925
40 RCL 04
41 -.117656
42 *
43 +
44 RCL 00
45 -1.04142
46 *
47 +
48 RCL 07
49 .311223 E-6
50 *
51 +
52 RCL 07
53 RCL 03
54 *
55 .876216 E-11
56 *
57 +
58 RCL 06
59 -.734593 E-5
60 *
61 +
62 RCL 06
63 RCL 03
64 *
65 .358246 E-9
66 *
67 +
68 RCL 05
69 -.00147462
70 *
71 +
72 RCL 05
73 RCL 00
74 *
75 .495106 E-4
76 *
77 +
78 RCL 05
79 RCL 01
80 *
81 -.451883 E-5
82 *
83 +
84 RCL 04
85 RCL 00
86 *
87 .0060469
88 *
89 +
90 RCL 04
91 RCL 01
92 *
93 -.000282418
94 *
95 +
96 RCL 01
97 .0268048
98 *
99 +
100 RCL 02
101 -.00063067
102 *
103 +
104 GTO 05
105♦LBL 03
106 23.346
107 RCL 04
108 -.0155989
109 *
110 +
111 RCL 00
112 -.1907
113 *
114 +
115 RCL 07
116 -.219767 E-6
117 *
118 +
119 RCL 07
120 RCL 00
121 *
122 .389472 E-8
123 *
124 +
125 RCL 06
126 -.769256 E-5
127 *
128 +
129 RCL 05
130 .000147492
131 *
132 +
133 RCL 01
134 -.00128983
135 *
136 +
137♦LBL 05
138 STO 24
139 X↑2
140 STO 25
141 X↑2
142 STO 26
143 .00559456
144 RCL 16
145 -.0756063
146 *
147 +
148 RCL 24
149 .999707
150 *
```

```
151 +
152 RCL 18
153 -.164715 E-4
154 *
155 +
156 RCL 17
157 RCL 24
158 *
159 .00038988
160 *
161 +
162 RCL 17
163 RCL 25
164 *
165 -.250156 E-4
166 *
167 +
168 RCL 17
169 RCL 26
170 *
171 .234975 E-7
172 *
173 +
174 RCL 16
175 RCL 24
176 *
177 .0103111
178 *
179 +
180 RCL 16
181 RCL 26
182 *
183 -.220855 E-6
184 *
185 +
186 STO 24
187 ENTER↑
188 ENTER↑
189 X↑2
190 *
191 STO 25
192 *
193 STO 26
194 .0278589
195 RCL 24
196 .998241
197 *
198 +
199 RCL 21
200 RCL 24
201 *
202 -.0018941
203 *
204 +
205 RCL 21
206 RCL 25
207 *
208 .425897 E-5
209 *
210 +
211 RCL 21
212 RCL 26
213 *
214 -.140897 E-6
215 *
216 +
217 23.0
218 X<=Y?
219 GTO 04
220 X<>Y
221 1000
222 *
223 "VTO GW="
224 ARCL X
225 ADV
226 RTN
227♦LBL 04
228 "VTO GW=23,000"
229 ADV
230 .END.
```

F. TORQUE REQUIRED TO HOVER IN GROUND EFFECT (HITQ)

1. Equations/Fit statistics-

Regression equation- For Figure 11-6 top chart [Ref. 4 p. 11-12].

$R^2 = .99941$

Standard error of estimate = .445612 % tq.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	-1.4252
C	3.17576
C^4	$.29445 \times 10^{-4}$
C^4D^2	$.862219 \times 10^{-7}$
C^3D	$.431755 \times 10^{-4}$
D^3	.000628288

Regression equation- For Figure 11-6 bottom chart [Ref. 4 p. 11-12].

$R^2 = .99997$

Standard error of estimate = .123506 % tq.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	-.0376377
E	.694891
M	1.00055
E^4	$-.163135 \times 10^{-5}$
E^4M^2	$.100327 \times 10^{-9}$
E^2	-.00298623
EM	-.0296401
EM^2	.000268863
EM^4	$-.647012 \times 10^{-8}$

2. Flowchart- See Figure B.6.

3. Program listing- See page 49.

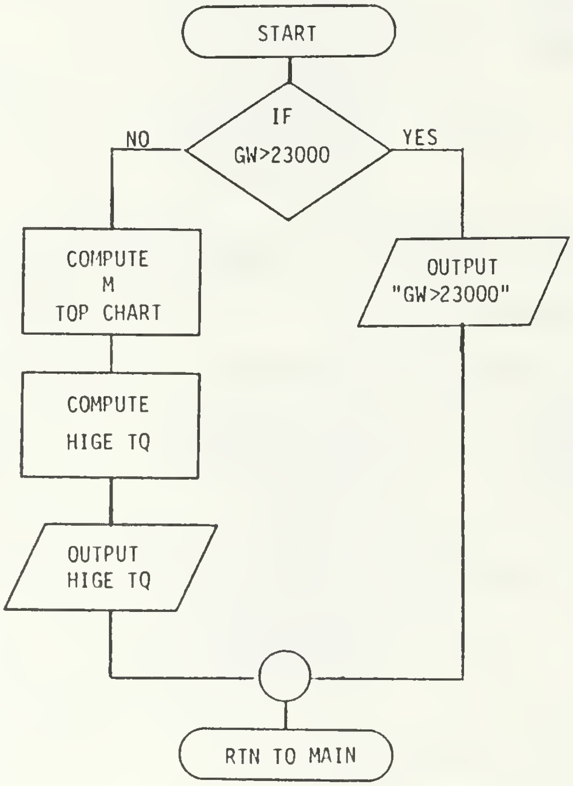

Figure B.6 HITQ Flowchart

```
01♦LBL "HITØ"
02 23
03 RCL 08
04 X<=Y?
05 GTO 03
06 "GW>23.000"
07 ADV
08 RTN
09♦LBL 03
10 -1.4252
11 RCL 08
12 3.17576
13 *
14 +
15 RCL 11
16 .2945 E-4
17 *
18 +
19 RCL 11
20 RCL 13
21 *
22 .862219 E-7
23 *
24 +
25 RCL 10
26 RCL 12
27 *
28 .431755 E-4
29 *
30 +
31 RCL 14
32 .000628298
33 *
34 +
35 STO 23
36 X↑2
37 STO 24
38 X↑2
39 STO 25
40 -.037637
41 RCL 16
42 .694891
43 *
44 +
45 RCL 23
46 1.00855
47 *
48 +
49 RCL 19
50 -.163135 E-5
51 *
52 +
53 RCL 19
54 RCL 24
55 *
56 .100327 E-9
57 *
58 +
59 RCL 17
60 -.00298623
61 *
62 +
63 RCL 16
64 RCL 23
65 *
66 -.0296401
67 *
68 +
69 RCL 16
70 RCL 24
71 *
72 .000268963
73 *
74 +
75 RCL 16
76 RCL 25
77 *
78 -.647012 E-8
79 *
80 +
81 "HIGE TØ="
82 ARCL X
83 ADV
84 .END.
```

G. TORQUE REQUIRED TO HOVER OUT OF GROUND EFFECT (HOTQ)

1. Equations/Fit statistics-

   Regression equation- For Figure 11-7 top chart [Ref. 4 p. 11-13].

   $R^2 = .99987$

   Standard error of estimate = .215589 % tq.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	15.0892
D	.108012
C^4D	$.18747 \times 10^{-5}$
C^4D^4	$-.520378 \times 10^{-8}$
C^3	-.00353622
C^3D^4	$.123336 \times 10^{-6}$
C^2	.226524
CD^2	.00162427
D^3	-.00265822

   Regression equation- For Figure 11-7 bottom chart [Ref. 4 p. 11-13].

   $R^2 = .99978$

   Standard error of estimate = .292877 % tq.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	-.0523486
E	-.30622
N	1.00117
E^4N^2	$-.434411 \times 10^{-9}$
EN^2	$-.266181 \times 10^{-4}$

2. Flowchart- See Figure B.7.

3. Program listing- See page 52.

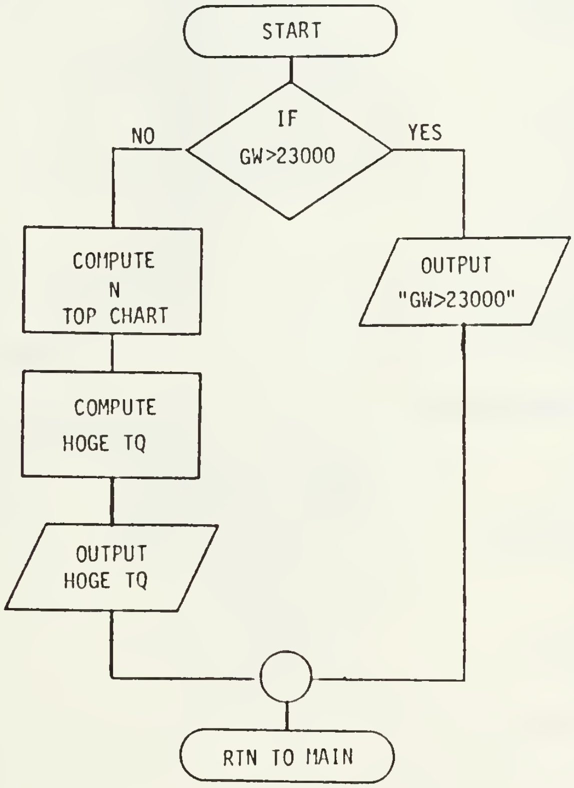

Figure B.7 HOTQ Flowchart

```
01♦LBL "HOTQ"
02 23
03 RCL 08
04 X<=Y?
05 GTO 03
06 "GW>23,000"
07 ADV
08 RTN
09♦LBL 03
10 15.0892
11 RCL 12
12 .108012
13 *
14 +
15 RCL 11
16 RCL 12
17 *
18 .18747 E-5
19 *
20 +
21 RCL 11
22 RCL 15
23 *
24 -.520378 E-8
25 *
26 +
27 RCL 10
28 -.0035362
29 *
30 +
31 RCL 10
32 RCL 15
33 *
34 .123336 E-6
35 *
36 +
37 RCL 09
38 .226524
39 *
40 +
41 RCL 08
42 RCL 13
43 *
44 .00162427
45 *
46 +
47 RCL 14
48 -.00265822
49 *
50 +
51 STO 23
52 X↑2
53 STO 24
54 -.0523486
55 RCL 16
56 -.30622
57 *
58 +
59 RCL 23
60 1.00117
61 *
62 +
63 RCL 19
64 RCL 24
65 *
66 -.43441 E-9
67 *
68 +
69 RCL 16
70 RCL 24
71 *
72 -.266181 E-4
73 *
74 +
75 "HOGE TQ="
76 ARCL X
77 ADV
78 .END.
```

H. MAXIMUM RANGE (RNG)

1. Equations/Fit statistics-

Regression equation- For Figure 11-13 bottom right [Ref. 4 p. 11-22].

$R^2 = .99773$

Standard error of estimate = .000884 nm/lb fuel.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	.1383
A	.00187702
C	-.00218126
A^3	-.000027957
AC^3	$-.62102 \times 10^{-7}$
A^4C^6	$.930331 \times 10^{-14}$
A^6C^2	$-.300259 \times 10^{-10}$
A^5C	$.106168 \times 10^{-7}$
A^3C^6	$-.279396 \times 10^{-12}$
A^2	.000307637

Regression equation- For Figure 11-13 bottom left [Ref. 4 p. 11-22].

$R^2 = .99995$

Standard error of estimate = .000166 nm/lb fuel.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	$-.423343 \times 10^{-4}$
P	1.00044
B	$-.403071 \times 10^{-4}$
P^4B	.277347
P^4B^4	$-.49131 \times 10^{-5}$
P^3B	-.0402217
P^3B^4	$.80486 \times 10^{-6}$
B^4	$-.421314 \times 10^{-9}$

Regression equation- For Figure 11-14 chart [Ref. 4 p. 11-23].

$R^2 = .99991$

Standard error of estimate = 1.045573 nm.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	.459586
F	.227375
FQ	99.6167

Regression equation- For Figure 11-13 middle right [Ref. 4 p. 11-22].

R^2 = .99676

Standard error of estimate = .703488 kts.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	116.811
A	-2.20562
A^3C^2	.0000960635
A^3C^4	$-.128465\times10^{-6}$
A^2C^3	-.0000375032
C^2	.0333256
A^6C^5	$-.121685\times10^{-10}$
A^6C^6	$.491492\times10^{-12}$
AC^5	$.404972\times10^{-5}$
AC^6	$-.174029\times10^{-6}$

Regression equation- For Figure 11-13 middle left [Ref. 4 p. 11-22].

R^2 = .99839

Standard error of estimate = .870905 kts.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	51.8923
B	-3.6787
R^4	$-.403206\times10^{-6}$
R^4B	$-.261757\times10^{-8}$
R^4B^3	$-.286464\times10^{-12}$
R^3	.0000882727
R^2B^2	$-.165604\times10^{-5}$
RB	.0330258
RB^2	.00045386
B^2	-.0356287

2. Flowchart- See Figure B.8.

3. Program listing- See pages 56-57.

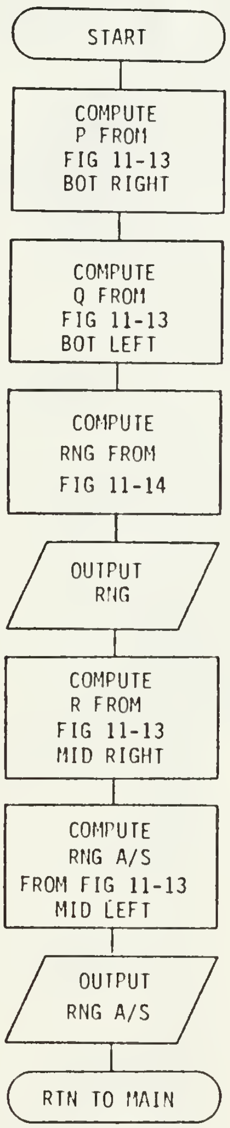

Figure B.8 RNG Flowchart

```
01♦LBL "RNG"
02♦LBL 01
03 RCL 02
04 X↑2
05 STO 23
06 RCL 10
07 X↑2
08 STO 24
09 .1383
10 RCL 00
11 .00187702
12 *
13 +
14 RCL 08
15 -.00218126
16 *
17 +
18 RCL 02
19 -.27957 E-4
20 *
21 +
22 RCL 00
23 RCL 10
24 *
25 -.62102 E-7
26 *
27 +
28 RCL 03
29 RCL 24
30 *
31 .930331 E-14
32 *
33 +
34 RCL 23
35 RCL 09
36 *
37 -.300259 E-10
38 *
39 +
40 RCL 00
41 5
42 Y↑X
43 RCL 08
44 *
45 .106168 E-7
46 *
47 +
48 RCL 02
49 RCL 24
50 *
51 -.279396 E-12
52 *
53 +
54 RCL 01
55 .000307673
56 *
57 +
58 STO 25
59 26.028
60 XEQ "QD"
61 -.423343 E-4
62 RCL 25
63 1.00044
64 *
65 +
66 RCL 04
67 -.403071 E-4
68 *
69 +
70 RCL 28
71 RCL 04
72 *
73 .277347
74 *
75 +
76 RCL 28
77 RCL 07
78 *
79 -.49131 E-5
80 *
81 +
82 RCL 27
83 RCL 04
84 *
85 -.0402217
86 *
87 +
88 RCL 27
89 RCL 07
90 *
91 .80486 E-6
92 *
93 +
94 RCL 07
95 -.421314 E-9
96 *
97 +
98 RCL 20
99 *
100 99.6167
101 *
102 .459586
103 +
104 RCL 20
105 .227375
106 *
107 +
108 "MAX RNG="
109 ARCL X
110 FS? 01
111 GTO 03
112 ADV
113 PROMPT
114 GTO 04
115♦LBL 03
116 ADV
117 PRA
118♦LBL 04
119 116.811
120 RCL 00
121 -2.20562
122 *
123 +
124 RCL 02
125 RCL 09
126 *
127 .960635 E-4
128 *
129 +
130 RCL 02
131 RCL 11
132 *
133 -.128465 E-6
134 *
135 +
136 RCL 01
137 RCL 10
138 *
139 -.375032 E-4
140 *
141 +
142 RCL 09
143 .0333256
144 *
145 +
146 RCL 23
147 RCL 08
148 5
149 Y↑X
150 *
```

```
151 -.121685 E-10
152 *
153 +
154 RCL 23
155 RCL 24
156 *
157 .491492 E-12
158 *
159 +
160 RCL 00
161 RCL 08
162 5
163 Y↑X
164 *
165 .404972 E-5
166 *
167 +
168 RCL 00
169 RCL 24
170 *
171 -.174029 E-6
172 *
173 +
174 STO 25
175 26.028
176 XEQ "QD"
177 51.8923
178 RCL 04
179 -3.6787
180 *
181 +
182 RCL 28
183 -.403206 E-6
184 *
185 +
186 RCL 28
187 RCL 04
188 *
189 -.261757 E-8
190 *
191 +
192 RCL 28
193 RCL 06
194 *
195 -.286464 E-12
196 *
197 +
198 RCL 27
199 .882727 E-4
200 *
201 +
202 RCL 26
203 RCL 05
204 *
205 -.165604 E-5
206 *
207 +
208 RCL 04
209 RCL 25
210 *
211 .0330258
212 *
213 +
214 RCL 25
215 RCL 05
216 *
217 .00045386
218 *
219 +
220 RCL 05
221 -.0356287
222 *
223 +
224 "RHG A/S="
225 ARCL X
226 ADV
227 .END.
```

I. MAXIMUM LEVEL FLIGHT ENDURANCE (END)

1. Equations/Fit statistics-

   Regression equation- For Figure 11-21 bottom chart [Ref. 4 p. 11-32].

   R^2 = .97211

   Standard error of estimate = .988268 kts.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	-563.098
I	2.74663
C	94.3518
A	48.7049
C^2	-4.6753
A^2	-.6005
C^3	.077392
AC	-4.49562
A^2C^2	.00153818
C^3A	.00927324
C^3A^3	$.769943 \times 10^{-5}$
I^3A	.0000905311
IA^2	.0262874
A^2I^3	-.0000161533
A^3I^3	$.191249 \times 10^{-5}$
IC	-.188195
ICA^3	.0000604516
ICA^2	-.00373104
C^3IA^2	.0000123564
IC^2A	-.00230188
C^3IA	.000205707
$I^4C^3A^3$	$.101077 \times 10^{-10}$
I^4CA	$-.102061 \times 10^{-6}$
$C^4A^3I^3$	$-.233492 \times 10^{-10}$
C^4AI	$-.476391 \times 10^{-5}$
I^4C	$.440832 \times 10^{-6}$
C^4I	$.550886 \times 10^{-5}$
C^4A	-.000212041
AC^2I^4	$.144642 \times 10^{-8}$
$A^2C^4I^3$	$.45315 \times 10^{-10}$
A^2C^4I	$-.285156 \times 10^{-6}$
$A^4I^2C^3$	$.81415 \times 10^{-10}$
$A^4I^2C^4$	$-.204801 \times 10^{-10}$
I^4	$-.782574 \times 10^{-5}$
I^4C^4	$-.487904 \times 10^{-11}$
I^3A^4	$-.107731 \times 10^{-6}$
C^4A^4	$.290421 \times 10^{-9}$
C^4A^3	$-.364546 \times 10^{-6}$
C^4A^2	$-.532767 \times 10^{-7}$

Regression equation- For Figure 11-21 top chart [Ref. 4 p. 11-33].

R^2 = .99959

Standard error of estimate = .095246 hrs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	-14.1228
A	-.540052
C	1.18957
A^2C^4	$-.294347\times10^{-7}$
AC	.0570829
AC^2	-.000939808
C^4	$-.70554\times10^{-5}$

Regression equation- For Figure 11-21 bottom chart [Ref. 4 p. 11-33].

R^2 = .99998

Standard error of estimate = .016675 hrs.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	-.00553605
T	1.00062
T^4I^4	$-.349348\times10^{-11}$
T^2I^2	$.158075\times10^{-5}$
TI	-.00117903
TI^2	$-.216546\times10^{-4}$
TI^4	$.847453\times10^{-8}$

2. Flowchart- See Figure B.9.

3. Program listing- See pages 61-63.

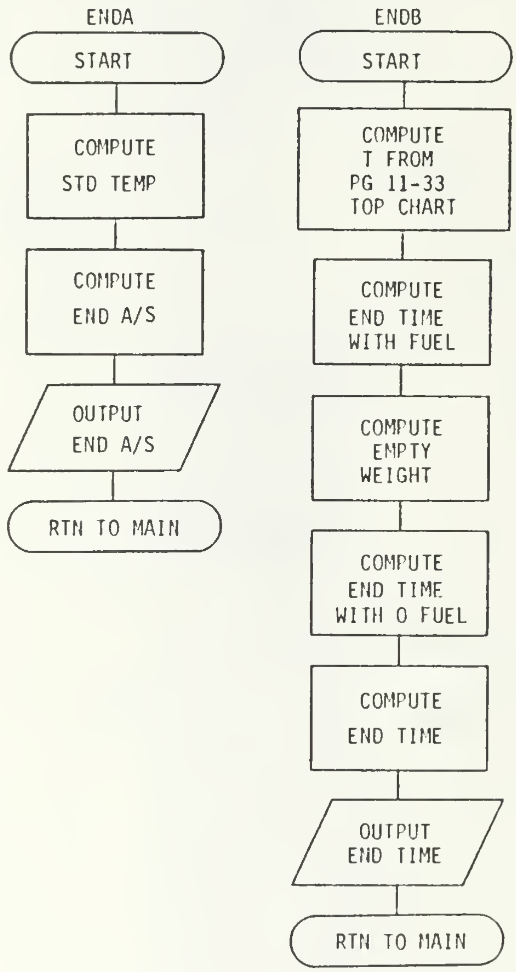

Figure B.9 END Flowcharts

```
01♦LBL "ENDA"
02 RCL 04
03 15
04 -
05 RCL 06
06 2
07 *
08 +
09 STO 23
10 STO 29
11 24.026
12 XEQ "QD"
13 20
14 RCL 23
15 X<=Y?
16 GTO 05
17 4
18 RCL 00
19 X<=Y?
20 GTO 05
21 8.001
22 X>Y?
23 GTO 01
24 GTO 02
25♦LBL 01
26 20
27 RCL 06
28 X<=Y?
29 GTO 05
30♦LBL 02
31 "OFF CHART"
32 ADV
33 RTN
34♦LBL 05
35 -563.098
36 RCL 23
37 2.74663
38 *
39 +
40 RCL 06
41 94.3518
42 *
43 +
44 RCL 00
45 48.7049
46 *
47 +
48 RCL 09
49 -4.6753
50 *
51 +
52 RCL 01
53 -.6805
54 *
55 +
56 RCL 10
57 .077392
58 *
59 +
60 RCL 00
61 RCL 08
62 *
63 -4.49562
64 *
65 +
66 RCL 01
67 RCL 09
68 *
69 .00153818
70 *
71 +
72 RCL 10
73 RCL 06
74 *
75 .00927324
76 *
77 +
78 RCL 10
79 RCL 02
80 *
81 .769943 E-5
82 *
83 +
84 RCL 25
85 RCL 00
86 *
87 .905311 E-4
88 *
89 +
90 RCL 23
91 RCL 01
92 *
93 .0262874
94 *
95 +
96 RCL 01
97 RCL 25
98 *
99 -.161533 E-4
100 *
101 +
102 RCL 02
103 RCL 25
104 *
105 .191249 E-5
106 *
107 +
108 RCL 23
109 RCL 08
110 *
111 -.188195
112 *
113 +
114 RCL 23
115 RCL 08
116 *
117 RCL 02
118 *
119 .604516 E-4
120 *
121 +
122 RCL 23
123 RCL 08
124 *
125 RCL 01
126 *
127 -.00373104
128 *
129 +
130 RCL 10
131 RCL 23
132 *
133 RCL 01
134 *
135 .123564 E-4
136 *
137 +
138 RCL 23
139 RCL 09
140 *
141 RCL 06
142 *
143 -.00230188
144 *
145 +
146 RCL 10
147 RCL 23
148 *
149 RCL 00
150 *
```

```
151 .000205707
152 *
153 +
154 RCL 26
155 RCL 10
156 *
157 RCL 02
158 *
159 .101077 E-10
160 *
161 +
162 RCL 26
163 RCL 08
164 *
165 RCL 00
166 *
167 -.102061 E-6
168 *
169 +
170 RCL 11
171 RCL 02
172 *
173 RCL 25
174 *
175 -.233492 E-10
176 *
177 +
178 RCL 11
179 RCL 00
180 *
181 RCL 23
182 *
183 -.476391 E-5
184 *
185 +
186 RCL 26
187 RCL 08
188 *
189 .440832 E-6
190 *
191 +
192 RCL 11
193 RCL 23
194 *
195 .550886 E-5
196 *
197 +
198 RCL 11
199 RCL 00
200 *
201 -.000212041
202 *
203 +
204 RCL 00
205 RCL 09
206 *
207 RCL 26
208 *
209 .144642 E-8
210 *
211 +
212 RCL 01
213 RCL 11
214 *
215 RCL 25
216 *
217 .45315 E-10
218 *
219 +
220 RCL 01
221 RCL 11
222 *
223 RCL 23
224 *
225 -.285156 E-6
226 *
227 +
228 RCL 03
229 RCL 24
230 *
231 RCL 10
232 *
233 .81415 E-10
234 *
235 +
236 RCL 03
237 RCL 24
238 *
239 RCL 11
240 *
241 -.204801 E-10
242 *
243 +
244 RCL 26
245 -.782574 E-5
246 *
247 +
248 RCL 26
249 RCL 11
250 *
251 -.487904 E-11
252 *
253 +
254 RCL 25
255 RCL 03
256 *
257 -.107731 E-6
258 *
259 +
260 RCL 11
261 RCL 03
262 *
263 .290421 E-9
264 *
265 +
266 RCL 11
267 RCL 02
268 *
269 -.364546 E-6
270 *
271 +
272 RCL 11
273 RCL 01
274 *
275 -.532767 E-7
276 *
277 +
278 "END A/S="
279 ARCL X
280 ADV
281 .END.
```

```
01♦LBL "ENDB"
02 RCL 29
03 STO 04
04 5.007
05 XEQ "QD"
06♦LBL 01
07 -14.12228
08 RCL 00
09 -.540052
10 *
11 +
12 RCL 08
13 1.18957
14 *
15 +
16 RCL 01
17 RCL 11
18 *
19 -.294347 E-7
20 *
21 +
22 RCL 00
23 RCL 08
24 *
25 .0570829
26 *
27 +
28 RCL 00
29 RCL 09
30 *
31 -.000939908
32 *
33 +
34 RCL 11
35 -.70554 E-5
36 *
37 +
38 STO 23
39 24.026
40 XEQ "QD"
41 -.00553605
42 RCL 23
43 1.00062
44 *
45 +
46 RCL 26
47 RCL 07
48 *
49 -.349348 E-11
50 *
51 +
52 RCL 24
53 RCL 05
54 *
55 .158075 E-5
56 *
57 +
58 RCL 23
59 RCL 04
60 *
61 -.00117983
62 *
63 +
64 RCL 23
65 RCL 05
66 *
67 -.216546 E-4
68 *
69 +
70 RCL 23
71 RCL 07
72 *
73 .847453 E-8
74 *
75 +
76 FC?C 03
77 GTO 02
78 CHS
79 RCL 27
80 +
81 STO 28
82 INT
83 "END TIME="
84 ARCL X
85 "⊢HR"
86 FS? 01
87 GTO 04
88 ADV
89 PROMPT
90 GTO 05
91♦LBL 04
92 ADV
93 PRA
94♦LBL 05
95 RCL 28
96 FRC
97 60
98 *
99 "       +"
100 ARCL X
101 "⊢MN"
102 RTN
103♦LBL 02
104 STO 27
105 RCL 08
106 RCL 20
107 10
108 /
109 -
110 STO 08
111 9.011
112 XEQ "QD"
113 SF 03
114 GTO 01
115 .END.
```

J. ABILITY TO MAINTAIN FLIGHT WITH ONE ENGINE (SE/EV)

1. Equations/Fit statistics-

Regression equation- For Figure 11-23 top chart [Ref. 4 p. 11-37].

$R^2 = .99926$

Standard error of estimate = .50233 % tq.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	69.3394
D	3.29399
C^4	.000125967
C^4D	$-.577415 \times 10^{-4}$
C^4D^2	$-.192526 \times 10^{-5}$
C^3D	.00245945
C^3D^2	$.424577 \times 10^{-4}$
C^2D^4	$.462872 \times 10^{-6}$
CD	-.662361

Regression equation- For Figure 11-23 bottom chart above base line [Ref. 4 p. 11-37].

$R^2 = .996$

Standard error of estimate = 1.225218 kts.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	449.498
$U^{-1}H^4$	-.0344426
H^{-2}	-31869.1
H^6	$-.295226 \times 10^{-4}$
U^7H^8	$.264768 \times 10^{-13}$
U^8H^8	$-.196344 \times 10^{-14}$
U^{-7}	46749423
U^{-8}	$-.349828 \times 10^{9}$
$U^{-5}H^5$	-29.0417
$U^{-5}H^8$	.0176142
$U^{-6}H$	1120118
$H^{-5}U^4$	-2663.33
$H^{-6}U^3$	381481
$H^{-8}U^4$	-1179202

Regression equation- For Figure 11-23 bottom chart below base line [Ref. 4 p. 11-37].

$R^2 = .99245$

Standard error of estimate = 1.47515 kts.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	8824.72
$\exp(U^{-4}H^3)$	61.1876
$\exp(U^{-4}H^4)$	22.1052
$\exp(U^{-3}H^2)$	5.78698
$\exp(U^{-3}H^4)$	$.835267 \times 10^{-12}$
$\exp(U^{-2}H^2)$	-2388.27
$\exp(U^{-2}H^3)$	$-.44832 \times 10^{-8}$
$\exp(U^{-1}H)$	-6109.32
$\exp(U^{-1}H^2)$	$.601748 \times 10^{-6}$
$\exp(H^{-1})$	-210.325
$\exp(2U^{-1}H)$	1954.4

2. Flowchart- See Figure B.10.

3. Program listing- See pages 67-68.

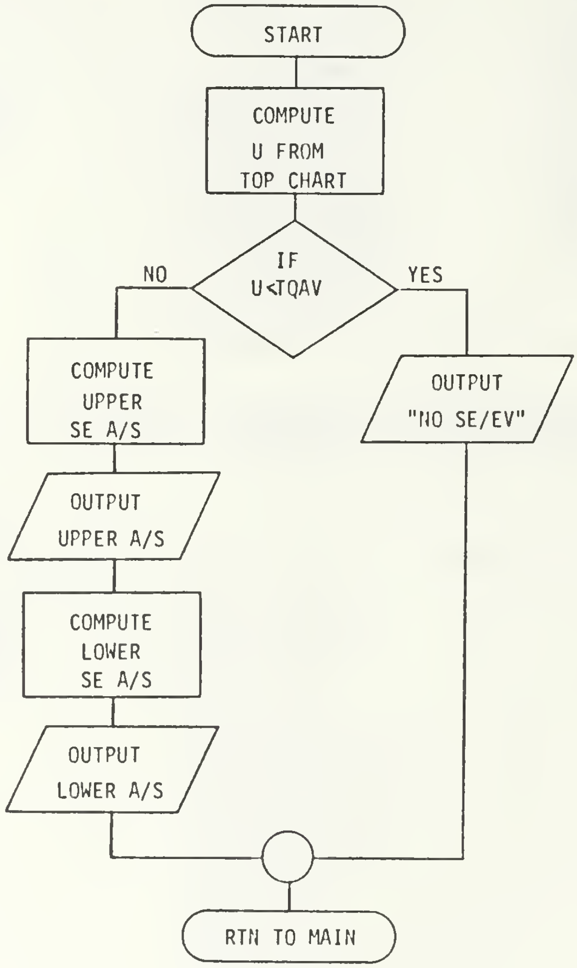

Figure B.10 SE/EV Flowchart

```
01♦LBL "SE/EV"
02 69.3394
03 RCL 12
04 3.29399
05 *
06 +
07 RCL 11
08 .000125967
09 *
10 +
11 RCL 11
12 RCL 12
13 *
14 -.577415 E-4
15 *
16 +
17 RCL 11
18 RCL 13
19 *
20 -.192526 E-5
21 *
22 +
23 RCL 10
24 RCL 12
25 *
26 .00245945
27 *
28 +
29 RCL 10
30 RCL 13
31 *
32 .424577 E-4
33 *
34 +
35 RCL 09
36 RCL 15
37 *
38 .462872 E-6
39 *
40 +
41 RCL 08
42 RCL 12
43 *
44 -.662361
45 *
46 +
47 10
48 /
49 STO 27
50 RCL 22
51 X>Y?
52 GTO 01
53 "NO SE/EV"
54 ADV
55 RTN
56♦LBL 01
57 23.025
58 XEQ "QD"
59 RCL 25
60 X↑2
61 STO 26
62 RCL 27
63 1/X
64 STO 27
65 28.030
66 XEQ "QD"
67 RCL 30
68 RCL 27
69 *
70 STO 31
71 449.498
72 RCL 27
73 RCL 25
74 *
75 -.034426
76 *
77 +
78 RCL 23
79 1/X
80 -31869.1
81 *
82 +
83 RCL 22
84 6
85 Y↑X
86 -.295226 E-4
87 *
88 +
89 RCL 27
90 -7
91 Y↑X
92 RCL 26
93 *
94 .264768 E-13
95 *
96 +
97 RCL 27
98 -8
99 Y↑X
100 RCL 26
101 *
102 -.196344 E-14
103 *
104 +
105 RCL 27
106 7
107 Y↑X
108 46749423
109 *
110 +
111 RCL 27
112 8
113 Y↑X
114 -.349828 E9
115 *
116 +
117 RCL 31
118 RCL 22
119 5
120 Y↑X
121 *
122 -29.0417
123 *
124 +
125 RCL 31
126 RCL 26
127 *
128 .0176142
129 *
130 +
131 RCL 27
132 6
133 Y↑X
134 RCL 22
135 *
136 1120118
137 *
138 +
139 RCL 22
140 -5
141 Y↑X
142 RCL 30
143 1/X
144 *
145 -2663.33
146 *
147 +
148 RCL 22
149 -6
150 Y↑X
```

```
RCL 29
1/X
*
381481
*
+
RCL 26
1/X
RCL 30
1/X
*
-1179202
*
+
"SE A/S="
ARCL X
FS? 01
GTO 04
ADV
PROMPT
GTO 05
•LBL 04
ADV
PRA
•LBL 05
8824.72
RCL 30
RCL 24
*
E↑X
61.1876
*
+
RCL 30
RCL 25
*
E↑X
22.1052
*
+
RCL 29
RCL 23
*
E↑X
5.78698
*
+
RCL 29
RCL 25
*
E↑X
.835267 E-12
*
+
RCL 28
RCL 23
*
E↑X
-2388.27
*
+
RCL 28
RCL 24
*
E↑X
-.44832 E-8
*
+
RCL 27
RCL 22
*
E↑X
-6109.32
*
+
RCL 27
RCL 23
*
E↑X
.601748 E-6
*
+
RCL 22
1/X
E↑X
-210.325
*
+
RCL 27
RCL 22
*
2
*
E↑X
1954.4
*
+
"   TO "
ARCL X
.END.
```

K. INDICATED NEVER EXCEED SPEED (VNE)

1. Equations/Fit statistics-

   Regression equation- For Figure 1-138 chart [Ref. 4 p. 1-173].

   $R^2 = .99959$

   Standard error of estimate = .483568 kts.

VARIABLE/ TRANSFORM	REGRESSION COEFFICIENT
INTERCEPT	93.7068
D	7.64496
D^4	-.000541484
C^3D^3	$.106803 \times 10^{-5}$
D^2	-.168473
C^2D	-.0383634
C^4D	$.251008 \times 10^{-4}$
C^2	.321101
C^4	-.000420052

2. Flowchart- See Figure B.11.

3. Program listing- See page 71.

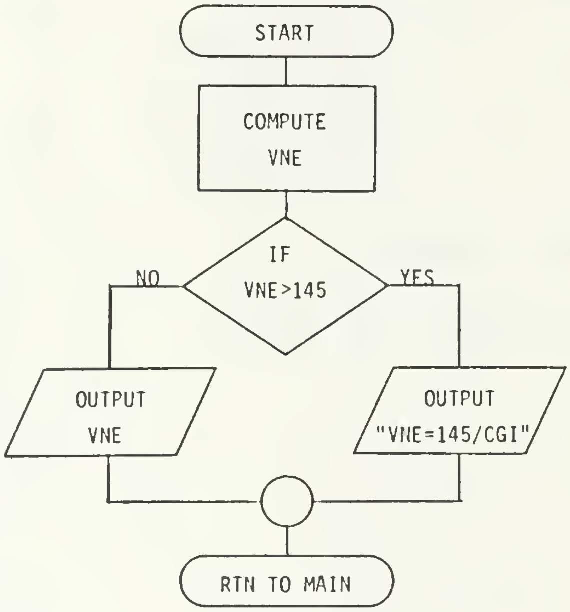

Figure B.11 VNE Flowchart

```
01♦LBL "VNE"
02 93.7068
03 RCL 12
04 7.64496
05 *
06 +
07 RCL 15
08 -.000541484
09 *
10 +
11 RCL 10
12 RCL 14
13 *
14 .106803 E-5
15 *
16 +
17 RCL 13
18 -.168473
19 *
20 +
21 RCL 09
22 RCL 12
23 *
24 -.0383634
25 *
26 +
27 RCL 11
28 RCL 12
29 *
30 .251808 E-4
31 *
32 +
33 RCL 09
34 .321101
35 *
36 +
37 RCL 11
38 -.000420052
39 *
40 +
41 145
42 X<=Y?
43 GTO 01
44 "VNE="
45 ARCL Y
46 ADV
47 RTN
48♦LBL 01
49 "VNE=145/CGI"
50 ADV
51 .END.
```

LIST OF REFERENCES

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9.	LCDR John T. Curtis, USN Naval Test Pilot School NAS Patuxtent River, Maryland 20670	1

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Thesis
C1963 Caram
c.1 Development of NATOPS performance software for the H-46D helicopter.